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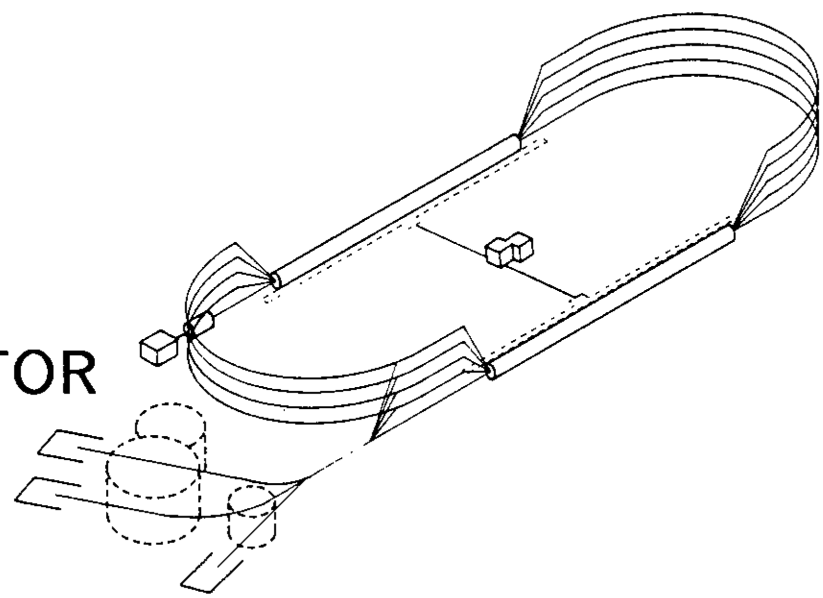

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Abstract

β=1 superconducting accelerator structures are traditionally operated immersed in a liquid helium bath. Nevertheless, several attempts have been made in the past to make use of the numerous operational and cost advantages of a pipe-cooling configuration: reduction in liquid helium inventory, minimized cooldown/warmup times, and elimination of the LHe-vessel, which reduces the sensitivity to microphonics and provides easier access to all cavity components.

This paper reports on tests performed with a 1500 MHz niobium cavity with 2K-LHe cooling channels covering only a fraction of the cavity surface. The cooling channels are made of niobium to preserve the capability for high temperature-treatments.

In the initial test the cavity was immersed in a helium bath; subsequently the cooling was only provided by superfluid helium in the cooling channels.

The experimental results are compared to thermal model calculations. In addition, the computer model is used to investigate the variations in cavity performance as a function of the cooling channel geometry and thermal conductivity properties of the niobium.

I. INTRODUCTION

The geometries of superconducting low-β structures such as helices [1], split rings [2], or quarter-wave resonators [3] allow the use of the structures themselves as a helium container for forced helium flow at 4.2 K. External parts, like couplers or the outer tanks, are cooled by conduction using composite materials like niobium explosion bonded to high thermal conductivity copper.

Superconducting β=1 accelerating cavities are traditionally cooled by immersion in a LHe bath. Early attempts were made to change this arrangement by building double-walled cavities [4,5] which still provided direct LHe cooling to the whole surface. Encouraged by the results of computer simulation calculations of the thermal effects on cavities made of niobium-copper composite material [6], further attempts to reduce the direct LHe contact cooling on 1000 MHz and 500 MHz cavities were made in the early 80's [7,8]. In these cavities cooling pipes for LHe at 4.2 K were attached to the outer cavity surface. In the first tests the outside niobium surface had been coated with high thermal conductivity silver; later a niobium-copper clad composite was used to take advantage of the high thermal conductivity of copper combined with the superior features for attachment of cooling channels by either brazing or electron beam welding. Even though these experiments were successful and demonstrated the feasibility of the pipe cooling concept at 4.2 K, they were not further pursued because of schedule pressure and budget constraints.

1500 MHz cavities have to be cooled down to superfluid helium temperatures in order to sufficiently lower the superconducting surface resistance of the material to achieve Q-values of $>5 \times 10^9$. At 2.0 K the thermal conductivity of niobium decreases to 20% of the value at 4.2 K. This imposes a stronger limitation on the spacing between the cooling channels especially if no copper layer is used.

Some of the advantages of a channel-cooled configuration are:

- Lower sensitivity to microphonics
- Capability of supporting higher pressures in the cryogenic system
- Easiliy recoverable low helium inventory
- Faster cooldown and warmup times
- Easier accessibility of components and diagnostics cables
- Reduction in the number of feedthrus for rf, tuners, and diagnostics
- Easier assembly and disassembly of cryostat

In the following sections we report on measurements carried out with a channel-cooled cavity, and compare the results with model calculations.

II. EXPERIMENTAL

A. Cavity

A single-cell 1500 MHz cavity with the CEBAF cell shape was modified to add cooling channels as shown in Figure 1.

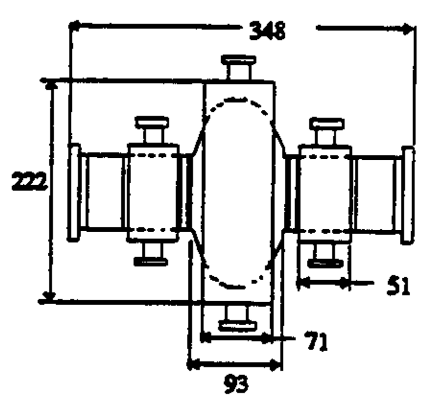

Figure1. Channel cooled cavity (dim. in mm).

The cell of the cavity was manufactured with high purity niobium with RRR > 220 supplied by Tokyo Denkai. The cell was postpurified at 1400°C for 4 hours in the presence of titanium as a solid getter material [9]. As indicated by measurement on samples, the thermal conductivity had improved by at least a factor of two after this treatment.

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B. Test sequence

A standard chemical surface treatment was applied to the cavity. It was subsequently attached to the cryogenic testing station and pumped to a vacuum of $<5 \times 10^{-7}$ torr. The first measurement of the Q-value as a function of rf field was done with the cavity fully immersed in LHe. In the second measurement, the cavity was cooled only by the LHe inside the cooling channels. Between these tests the cavity remained under vacuum, and no changes in the test arrangement except for the cooling were made. The test arrangement is shown schematically in Figure 2.

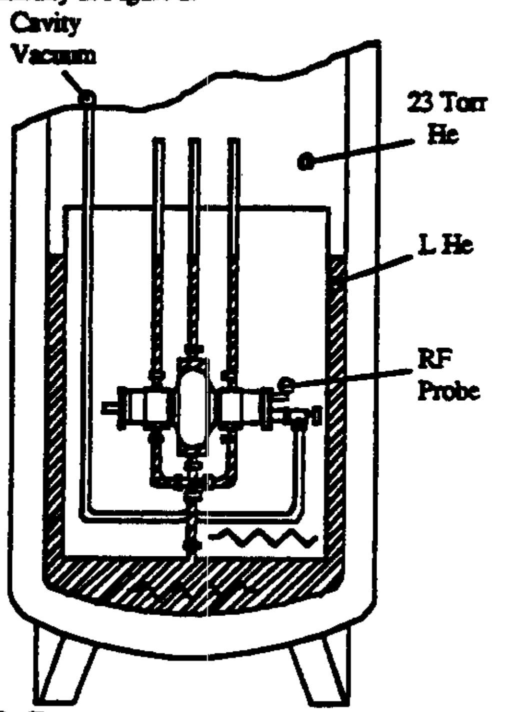

Figure 2. Test arrangement.

C. Measured results

Experimental results are shown in figures 3 and 4. The fully immersed cavity reached a peak surface field of E_{peak}=55 MV/m at 2.0 K, and 57 MV/m at 1.8 K. When the cavity was cooled only through the cooling channels, it performed as well as the immersed cavity up to a the peak surface field E_{peak}= 27 MV/m at 2.0K, and E_{peak}=35 MV/m at 1.35 K. Pulsed-rf operation increases significantly the attainable fields as shown in Figure 4.

D. Computer modeling

Several alternative geometries can be explored with the aid of computer modeling. A program developed for pipe-cooled Nb-Cu cavities [10] was modified and adapted to the channel-cooled niobium cavity.

The results obtained by varying several parameters are shown in Table 1.

The experimental model parameters are taken to calculate the base case. It is defined by a He-bath temperature=2.0 K, wall thickness=3.2 mm, cooling channel length=100 mm, and a niobium thermal conductivity of 40 W/m/K at 2 K. This case shows a three percent reduction in Q_0 at a peak field E_{peak}=18 MV/m and agrees very well with the experimental results, (Figure 5). For all other cases presented in Table 1, one property was changed from the base case. A reduced bath

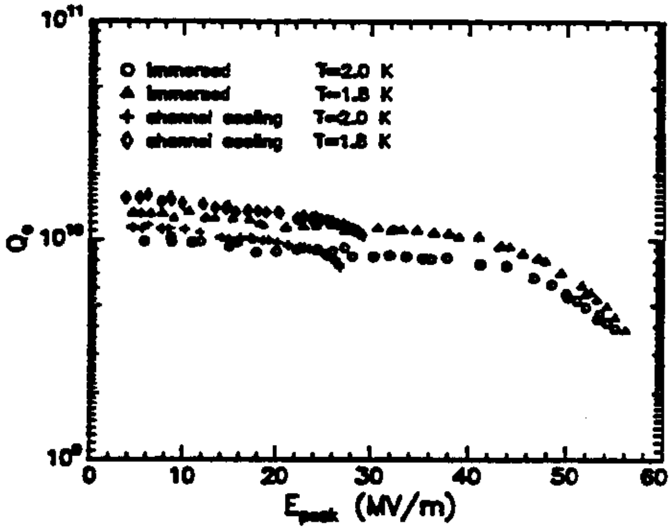

Figure 3. Q_0 as a function of peak surface field E_{peak} for the tested cavity at 2.0 K and 1.8K.

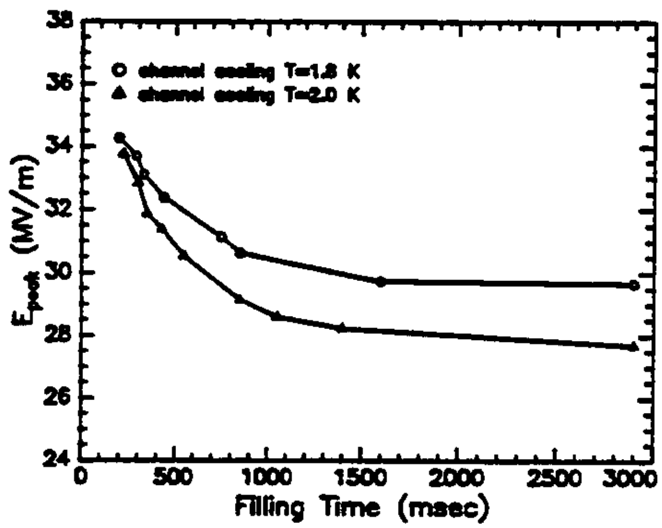

Figure 4. RF-peak surface field vs. rf-pulse length (50% duty cycle).

temperature of 1.8 K gives the predicted improvement in Q_0. The most critical factor is shown to be the size of the cooling channel. Other factors investigated showed little deviation from the base case up to the maximum calculated field.

The defect was modeled as a 400 mm^2 ring located 12 mm from the central cooling channel. The defect element contributed 0.5 W to the power dissipated at an E_{peak} of 9 MV/m.

III. CONCLUSION

The test results confirm the computer calculations. They indicate that a channel-cooled cavity made from high thermal conductivity niobium can perform nearly as well as a fully immersed cavity up to cw peak surface fields of 27 MV/m,

TABLE 1. Computer model results

	FULLY IMMERSED AT 2K	EXPER. CASE	Case 2	Case 3	Case 4	Case 5	Case 6	EXP. MODEL W DEFECT
		k=40 Tb=2 Cl=100 th=3.18	k=70 Tb=2 Cl=100 th=3.18	k=40 Tb=2 Cl=100 th=4.18	k=40 Tb=2 Cl=100 th=2.18	k=40.5 Tb=1.8 Cl=100 th=3.18	k=40 Tb=2 Cl=76 th=3.18	k=40 Tb=2 Cl=100 th=3.18
E_p Qo x 10^9 P	9 10.091 0.2815	9 10.027 0.2833	9 10.032 0.2832	9 10.032 0.2832	9 10.020 0.2835	9 15.027 0.1891	9 9.971 0.2849	9 3.527 0.7952
E_p Qo x 10^9 P	18 10.091 1.126	18 9.831 1.156	18 9.856 1.153	18 9.851 1.154	18 9.797 1.160	18 14.820 0.767	18 9.580 1.186	18 3.51 3.391
E_p Qo x 10^9 P	36 10.091 4.504	27 9.486 2.695	36 9.101 4.995	29 9.456 3.076	22 9.660 1.694	25 14.546 1.531	20 9.461 1.453	25 2.631 8.464

Tb=helium bath temperature (Kelvin) Cl=channel length (mm) $E_p=E_{peak}$ (MV/m)
k=channel conductivity at Tb (W/m/K) th=wall thickness (mm) P=dissipated power (watts)

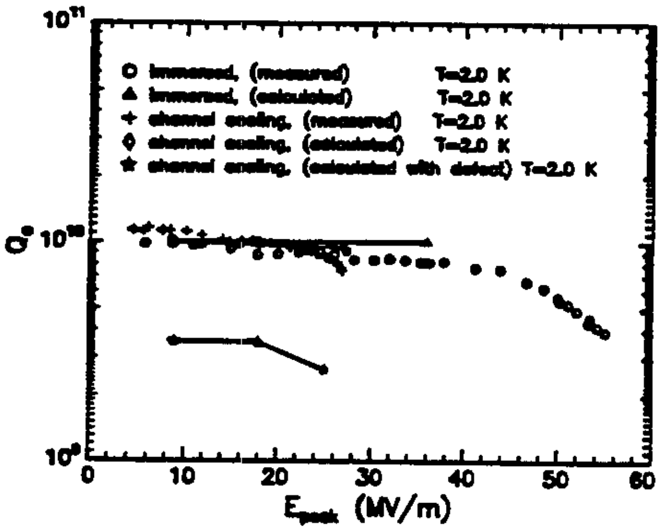

Figure 5. Calculated results at 2.0K (base case).

with a Q_0-value of 10×10^9 at 1.8 K, as measured in our experiments. This would correspond to an accelerating gradient of 10—11 MV/m in a 5-cell CEBAF cavity. Pulsed RF operating modes would allow significantly higher fields.

The channel configuration can be further optimized to support higher helium pressures and also to increase the cell mechanical stability. The cost savings in the cryogenic system, as well as in the cryostat fabrication and assembly, could offset the higher material and fabrication costs of the cavities.

IV. AKNOWLEDGEMENTS

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